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Low Cost Simplified Design of a Two Stage Plug Flow Gasifier

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Abstract

The process of coal gasification for synthetic gas production is currently seeing renewed interest due to the possibility it offers as a clean coal technology. The technology faces some financial challenges if it is to replace traditional pulverised coal combustion as a method for power generation without the help of government subsidisation. The report set out to investigate the aspects of gasifier design which provided high capital costs and to look at ways in which new future technology might be able to reduce these. The report consequently completed a preliminary design of a new novel gasifier, which was based on the findings.

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Keywords Gasification, Plug flow, Power generation

Introduction

Coal gasification is a technology which is recently receiving new interest from the scientific and engineering community as a method of developing synthetic gas and liquid fuels. The reason behind the renewed interest in what is a particularly old and relatively unused technology (in the energy sector) can be attributed to both fossil fuel prices and carbon emissions [1].

Currently, the use of coal in power generation accounts for approximately 42% of all global consumption whilst also accounting for 28% of CO_2 emissions [2]. With a projected increase of 70% in electricity consumption predicted by 2035 [3], and new legislation for lower CO_2 emissions being introduced, a significant amount of focus is being placed on the use of gasification in power generation as a future method of clean power generation [4]. Currently however, it has been shown that the use of gasification for power generation is not economically viable without the inclusion government incentives [5]. Due to this, further cost reductions of gasifier equipment are required to improve the commercial attractiveness of the technology. The use of a plug flow reactor has shown to reduce the overall volume required for reaction [6]. This provides capital cost savings and also enables the possibility of offsite fabrication due to transportation availability [7].

Most entrained flow gasifiers operate using oxygen rather than air for the combustion reactions [6]. This requires the use of an air separation unit which is a significant part of the capital cost of the gasification equipment [6]. Other sources also show that the net plant efficiency can be increased when using air rather than oxygen [8]. Upon completion of the endothermic gasification reactions, the hot gas needs to be cooled in order to be further processed. Several newer gasifiers use endothermic char reactions as a method of cooling the gas rather than water quenching which does not recover any sensible heat.

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The following gasifier design attempts to incorporate the features of an air blown, plug flow and two stage system in order to reduce the overall costs and improve efficiency.

Design Methodology

The initial stages of the gasifier design is primarily focused on the development of a single stage plug flow device which will later have the addition of a second coal slurry stage input incorporated into it (Figure 1). The modelling of the plug flow characteristics can be achieved using the concept of multiple free turbulent jets which converge to a single plug flow, Figure 3.

The design calculations require the use of pre-defined parameters such as operating temperature, pressure, Reynolds number and estimated required particle residence time. Using these, together with a combination of Equations 1 to 5, it is possible to determine the required volume of the gasifier as well as the physical dimensions.

Once the physical dimensions and determined jet velocities are obtained, a computational fluid dynamics (CFD) simulation of the single stage device can be achieved. Using data from the CFD simulation, the point at which the endothermic char reactions are complete can be found. The point at which the endothermic reactions subside represents the distance at which the second stage coal slurry addition requires to be placed. Using this information, together with a required gas output temperature, a calculation can be made to determine the required flow rates of water and coal using an energy balance of sensible and endothermic heats. Consequently, a CFD simulation of the second stage is now possible and can be used to determine whether a full conversion of the char particles is completed within the length of the gasifier. If this is not achievable, an adjustment of the gasifier dimensions is required.

Using temperature data from the second stage CFD simulation, it is possible to complete an estimate of the heat transfer rate from the gasifier body. The heat transfer of a hot gas can be assumed to be almost completely radiant [9] which consequently gives Equation 6 as the heat transfer rate from the gas. As the gas is a mixture which changes in composition along the gasifier length it was assumed that the gas was solely carbon monoxide which is typically one of the main constituents [6]. Using data from other literature [10], an estimate of the gas emissivity can be found at varying temperatures and pressures from Figure 2.

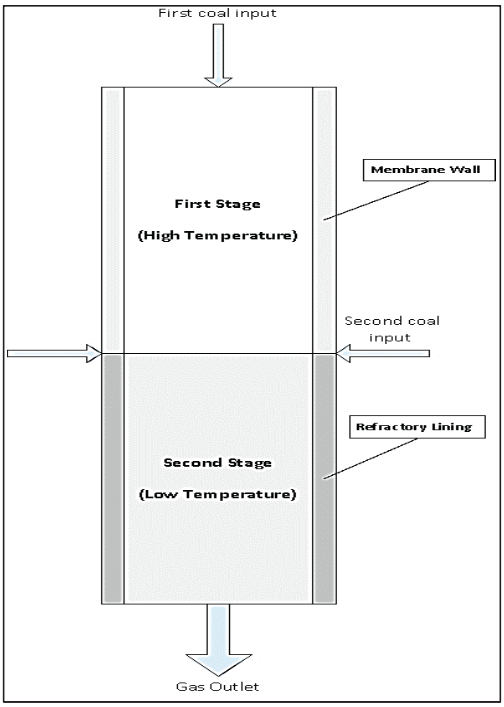

Figure 1: Gasifier design concept

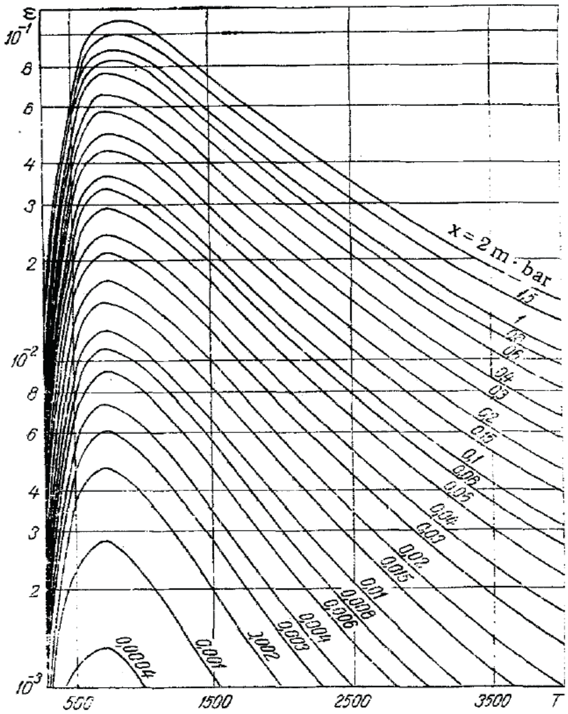

Figure 2: Nonogram of carbon monoxide emissivity

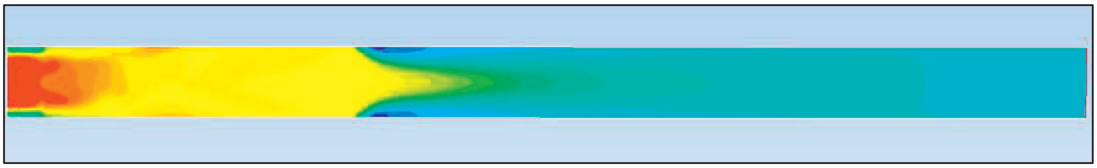

Figure 3: Turbulent jet arrangement

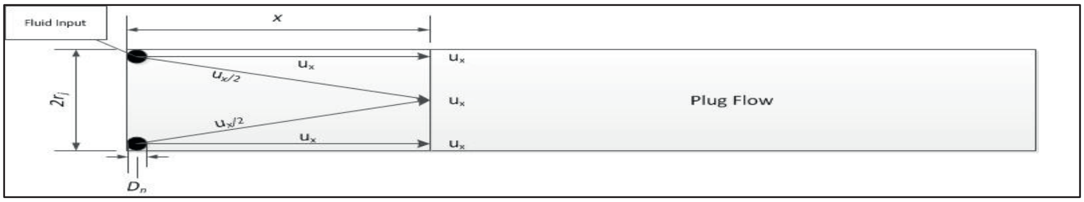

Figure 4: Plug flow x-velocity result (single stage)

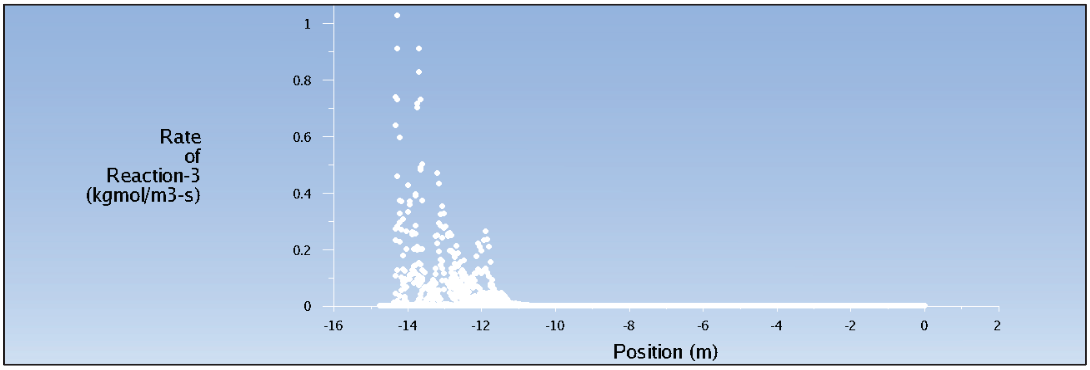

Figure 5: Reaction rate of endothermic reactions (single stage)

Figure 6: Gas temperature (two stage)

Results / Discussion **Conclusions**

The results indicate that the use of turbulent jets for an initial design model provide the predicted plug flow characteristics. Figure 4 shows the x-velocity pattern from CFD analysis of the single stage design which has a near constant velocity profile from the approximate convergence point estimated from the free turbulent jet model. This result demonstrates that the free turbulent jet model a simple but effective prediction of plug flow with simple geometry. This result was also confirmed with CFD data for average particle residence time, which was similar to that of the value set in the design methodology.

Figure 5 show the data of reaction rate from the single stage CFD simulation. The plot shows the drop off in reaction rate at a certain distance along the gasifier length and as such can be interpreted as the location where the second stage input is required. This result can be verified as the CFD output data showed a char conversion of approximately 99% throughout the gasifier.

Following the second stage CFD analysis, Figure 6 shows the gas temperature throughout the gasifier body. The temperature found at the gasifier exit approximately agreed with the prediction using sensible and endothermic heat energy balance and can be adjusted easily depending on gas post processing requirements. Using the temperature data, the heat transfer rate was calculated for the different temperature sections. The results of these would require experimental data to compare and as such are a work in progress.

The results discussed above show that the initial design shows validity that the use of air as an operating medium with a two stage plug flow system is feasible and as such may also provide some cost reductions based on previous research. The work requires further investigation of the detailed results and comparison with an experimental model to test these.

The report has found that the simple modelling of plug flow as a set of free turbulent jets yields a good approximation with results from CFD analysis. The report has also found that the use of air as an operating medium rather than oxygen is possible in a two stage plug flow operation. The report suggests that a small experimental scale device would provide very useful data regarding comparison of results.

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